627

VOLUME 81 SEPARATE No. 627

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

FEBRUARY, 1955

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HYDRAULICS DIVISION

{Discussions open until June 1, 1955}

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Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

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MODERN METHODS OF DEVELOPING GROUND-WATER SUPPLIES

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INTRODUCTION

Since early times, the development of a ground-water supply has been largely a matter of digging or drilling a well near the point of contemplated use and hoping for the best. Often, the choice of a well site was based on no sounder reasoning than that offered by a water diviner. Generally, no consideration whatever was given to the quantitative phases of the problem.

Even today, many ground-water developments are undertaken without utilizing well-established methods that largely eliminate many of the uncertainties which were present in the old "hit or miss" approach. Although much still remains to be learned about ground-water hydrology, modern methods of establishing a dependable ground-water supply offer great advantages over the older "trial and error" methods.

In contrast with earlier years, it is now generally recognized that a ground-water supply may be just as feasible for a large development as surface water. If hydrologic conditions are favorable, ground water may be more desirable and more economical than surface water because little or no treatment is generally required, initial cost is usually less (no large dam, filtration plant or long aqueduct) and its lower and more constant temperature may be important for industrial use. In a public water-supply system, scattered wells throughout the consuming area reduce the expense of major pipelines and give better pressure distribution during periods of peak demand. Many public water-supply systems using surface water are now augmenting their supply during peak periods by drilling wells at favorable sites in those areas where their distribution mains are inadequate. Relatively small quantities of ground water available for short periods at points of peak demand may be of great value in many water-supply systems.

In semi-arid regions there may be large underground reservoirs available for use where no surface water supplies can be developed economically. Even if the annual rate of recharge to such underground reservoirs is small, their total capacity may be so enormous that many years of pumping from storage can be carried on, just as many other non-replenishable natural resources are utilized.

Choice of Area to be Developed

Choosing an area in which the geologic and hydrologic conditions are favorable for the desired quantity and quality of water is the first and perhaps the most important question for consideration. However, in many cases no choice of area is involved because the ground-water investigator is asked to study and report on the ground-water conditions in the vicinity of an existing installation in need of additional water.

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Although numerous factors other than the availability of water must be considered in the choice of a new industrial site, an adequate and reliable supply of water is one of the most basic factors that should be soundly evaluated before the final choice of a plant site is made. Surprising as it may seem, there have been numerous instances where, after no more than casual consideration of availability of water, plant sites have been selected and purchased, only to find later on that the site is unsatisfactory because of inadequate water supply. Generally, the final choice of a plant site should not be made until at least a reconnaissance survey of water-supply conditions has been made at a number of alternate sites.

Municipalities or industries generally are desirous of developing a supply of ground water convenient to their plant site so as to avoid large expenditures, such as the cost of long pipelines. Every effort should, of course, be made to choose an adequate site as near to the contemplated point of use as is practicable. However, the hydrologist responsible for recommending a site should not be swayed in his evaluation of water-supply potentialities by the natural desire for economy on the part of others. Areas favorable for large ground-water supplies are the result of natural geologic and hydrologic conditions and to utilize the available resources of a potential area, one must either locate in favorable areas or convey the water to more distant points.

Because all ground water occurs in natural reservoirs beneath the land surface, ground-water problems are basically geologic. The composition and structure of the geologic units in an area often control in great measure the quantity and quality of water available.

In the initial consideration of the ground-water supply potential of an area all available geologic and hydrologic information should be carefully studied. Basic data on types of rock, thickness of formations, continuity of formations, faulting and other structural features should be considered. Published geologic maps may indicate quite clearly that the formations at the site in question are of a type that will not support the magnitude of the contemplated ground-water development. On the other hand, as in some glaciated areas, favorable potentialities may be inferred from the type of surficial deposits. Records of precipitation and stream flow in the area may have important bearing on a tentative appraisal of the ground-water conditions.

The geology and hydrology of the area being considered for development may be well known or described in detail in published reports. Much geologic and hydrologic information is available in reports or in the files of Federal and State organizations. However, in some areas, particularly in foreign countries, little or no information may be available and the investigator must carry out a field reconnaissance before making a tentative appraisal of the ground-water potential.

Not all of the areas where detailed ground-water investigations have been carried on are favorable sites for a new development. Frequently, such areas have been intensively studied because they are trouble spots where large ground-water developments are already in operation. In such areas, additional development may be unwise unless the dependable yield has not been approached. Even if additional developments can safely be made, consideration should be given to the possibility of costly litigation resulting from a new development.

Careful consideration must be given to the climatic conditions in the area being considered. If the contemplated ground-water development is to have a dependable yield year after year, the average annual recharge to the producing aquifers must be sufficient to sustain the rate of pumping. Areas of

recharge and the source of recharging water (precipitation or river infiltration) must be determined. Of great importance in some areas is the possibility of utilizing surface water or treated sewage for artificially recharging a ground-water reservoir. In places, the net rate of withdrawal is being considerably reduced by returning to the ground all ground water used for air-conditioning or industrial cooling.

In areas where large quantities of ground water are available as a non-replenishable resource, heavy pumping from storage may be feasible if the pumping wells are not too closely spaced. Under such conditions, however, it should be recognized that a progressive decline of ground-water levels will occur and that ultimately (perhaps 100 years or more later) the resource will be exhausted or the increased pumping lift will become uneconomical.

River alluvium, particularly in glaciated areas, may be highly permeable and capable of yielding large quantities of water. Although recharge from precipitation may be limited because of the small areal extent of the alluvial deposits, such sediments, if hydraulically interconnected with the river, may furnish large quantities of water by river infiltration. Under conditions of induced river infiltration the alluvium acts as a natural slow sand filter that is often quite effective in removing organisms and industrial wastes. If the geologic conditions are favorable for river infiltration, a ground-water development near the shore of the river will generally be much less expensive, both in initial cost and in operating cost, than a filtered supply using river water directly.

If the site being considered for a ground-water development is in the vicinity of bodies of salt water or in an area where some of the formations are known to contain saline water, careful consideration must be given to the geologic conditions, the relation between fresh and salt water and the probable changed relations under conditions of heavy pumping. The regional drawdown produced by heavy pumping may reverse the natural ground-water gradients and result in salt-water encroachment. However, it should be remembered that for many years large quantities of fresh water have been withdrawn in numerous areas that are relatively near the ocean without producing salt-water encroachment.

The movement of salt water into an aquifer as a result of pumping is generally a slow process sometimes involving many years. Therefore, in areas where there is likelihood of salt-water encroachment, outpost wells should be constructed between the producing wells and the source of salt water so that samples of water for chloride analysis can be taken at regular intervals. An adequate group of outpost wells should give advance warning if salt-water encroachment is taking place and thus provide a basis for reducing the pumping rate before the production wells have become salted. The proper spacing of wells to avoid mutual interference becomes increasingly important in areas near salt water, so that pumping water levels can be held to a minimum. Vast quantities of fresh water are continuously discharged to the sea through some Coastal Plain aquifers but even here heavily concentrated pumping can reverse normal gradients and permit salt-water encroachment.

Although the available information may be adequate for a tentative appraisal of the ground-water conditions of an area, additional detailed field investigation is generally necessary before a reliable appraisal of the ground-water potential can be made. Even in those areas for which considerable ground-water information is available, it is often necessary to make a field investigation and inspection of the site under consideration. First hand inspection of the significant geologic and hydrologic features in the field may

contribute greatly to an understanding of the problem. Often an inventory of the more important wells in the area is of great value in determining the nature and extent of exploratory work that may be necessary.

Most of the critical ground-water problems existing today are the result of excessive development by a large number of wells concentrated in a relatively small area. Excessive interference between nearby wells and the development of large areas of regional drawdown have resulted in costly overdevelopment and expensive litigation. Insofar as possible, present day or probable future critical areas should be avoided when choosing a site for a new development.

A final decision in selecting an area for a proposed ground-water development should not be made until the availability of the required quality and quantity of water has been determined with certainty. Ordinarily, this cannot be done until a certain amount of test drilling, test pumping and other exploratory work has been carried out.

Prospecting

In the last decade or so, new methods have become available as aids in prospecting for ground-water supplies. These include improved techniques in test drilling and sampling, geophysical surveying and quantitative hydraulic analysis of pumping test data. Sound application of these new methods as adjuncts to the older well-established methods permits the present day investigator to evaluate the ground-water potential of an area more accurately, more rapidly and at less cost. The new methods of approach now available may be of great assistance in the test drilling or exploration phases of an investigation, in obtaining quantitative results on the dependable yield of an aquifer and predicting the decline of ground-water levels that will take place in future years as a result of heavy pumping.

Preliminary consideration having been given to all geologic and hydrologic information available for the area, a field reconnaissance should then be made to obtain first hand information and inspect the pertinent features that determine the ground-water conditions. Examination should be made of areas where aquifers or confining beds crop out, of the relation between ground water and streams, of existing wells and springs and other significant features. Often data on well performance, well logs and analyses of water can be obtained from well owners or well drillers.

Usually, a reconnaissance survey will furnish a general understanding of the ground-water conditions and indicate whether there is need for additional detailed test drilling or other exploration work. Commonly, test wells will be needed to provide more detailed geologic and hydrologic information or to permit pumping tests to be carried out at the site to be developed.

The drilling of test wells often becomes an important part of the exploratory work because the composition and thickness of the available aquifers may not be known. Test wells may be needed so that pumping tests can be carried out to provide quantitative estimates, to provide information on quality of water or to permit the determination of ground-water gradients.

The type of test well best suited for the particular job varies greatly, depending on the geologic and hydrologic conditions and the purpose for which the test well is intended. Under certain conditions, relatively inexpensive dug holes or small-diameter jetted or drive-point wells may be satisfactory. Under other conditions, more costly deep wells may be necessary to provide the desired information. Generally, test wells about 100 feet or more in depth are put down by the cable-tool method, conventional rotary method or

the newer reverse-circulation method of rotary drilling, although in some areas other methods are in common use. Shallower test wells are often satisfactorily put down by jetting, by driving, by auger or by crane and orange-peel bucket. Depending on the use of the test well, it may be finished with a regular well screen, perforated pipe or merely with open-end pipe. In hard rock aquifers, the hole is generally uncased except near the surface.

If one of the chief purposes of a test well is to determine the character of the material penetrated, a method of drilling should be selected that will furnish reliable samples. In some cases, the taking of core samples may be desirable, in others, bailer samples from cable-tool drilling or mud ditch samples from rotary drilling may be adequate. Electric logs of uncased rotary holes may be of great value in interpreting the characteristics of the material penetrated or in correlating the logs of a group of test wells.

If a test well in unconsolidated material is to be used as a production well during a pumping test, it is generally finished with a temporary screen or perforated pipe and subjected to a moderate period of development by surging or other method of agitation.

If the ground-water conditions in the area being explored are not well known, numerous test wells may have to be drilled to adequately establish the characteristics and extent of the aquifer. In some hard rock aquifers with fracture or solution type openings, even if well known, a number of test wells may have to be drilled before the maximum yield to be expected at the site is established.

During the drilling of a test well, it sometimes is desirable to sample the water that is encountered at different depths. This can be done by setting packers so as to isolate the particular depth from which a sample is desired.

Geophysical methods of prospecting may be used to good advantage in the exploratory phases of some investigations. Where considerable test drilling is necessary, geophysical surveys may provide a basis for a better selection of drilling sites and thus reduce the number of test wells required. However, geophysical exploration does not eliminate the need for test drilling to provide positive and direct information on the geology of the area. Moreover, because test wells are commonly required for pumping tests to obtain quantitative results, it may be more economical to proceed directly with a test-drilling program without preliminary geophysical surveys.

In glaciated areas the most productive aquifers commonly occur in the buried bedrock valleys filled with glacial outwash. Preliminary geophysical surveys may locate the deepest parts of the buried valleys where producing aquifers are likely to occur. Such surveys may also give strong indication of the location of bodies of sand and gravel in the outwash deposits. Fault zones may form impermeable boundaries or highly fractured zones that are water bearing. Geophysical surveys may be of great aid in locating such fault zones. In coastal areas where fresh water is in contact with underlying salt water, the contact between the fresh and salt water may be determined by geophysical surveys.

Electric logging of uncased rotary wells is commonly practiced in some parts of the country. Careful study of such logs may assist in making geologic correlations from well to well, locating permeable zones and in studying the relationship between fresh and salt water. In cased wells, gamma ray logging has been used as an aid in interpreting the kind of materials penetrated.

In recent years, the quantitative approach to ground-water problems has been greatly improved by the development of pumping-test methods that

provide a means of determining the more important characteristics of an aquifer. These methods all involve carefully controlled pumping tests during which accurate measurements of the yield of the pumping well and of the water level in a number of observation wells are made frequently. Depending on geologic conditions, such tests may cover a period of a day to a few days or more. Under certain conditions, some of the methods require frequent measurements of water level at the start of the test and during the first part of the recovery period after pumping is stopped.

The more important aquifer characteristics determined by the pumping tests are the coefficient of permeability, the coefficient of transmissibility and the coefficient of storage. The coefficient of permeability is usually expressed as the number of gallons of water a day that percolates through a cross sectional area of one square foot under a hydraulic gradient of 100 percent. For convenience in the practical application of this factor the coefficient of transmissibility is generally used in field tests. The coefficient of transmissibility is equal to the coefficient of permeability multiplied by the thickness of the saturated portion of the aquifer. The coefficient of storage is defined as the number of cubic feet of water discharged from each vertical column of the aquifer with a base one foot square as the water level falls one foot.

The mathematical treatment involved in all of the pumping test methods requires certain assumptions as to ideal conditions, some of which are, that the aquifer is homogeneous, that it is infinite in extent and that it has the same transmissibility at all places. Because these and other assumptions are generally not entirely valid, the results of different tests in the same area are sometimes not identical. The observed variations from the results that would occur if the assumed conditions did exist give the experienced investigator an insight into actual variations in geologic conditions from place to place, which determine the characteristics of the aquifer. The several assumptions involved and the latitude possible in interpreting the observed data require that great care must be used in making practical application of the quantitative results of pumping tests. However, the pumping-test approach to ground-water supply problems is perhaps the most valuable method available to the experienced investigator.

Methods of Development

Recommendations for the best method of developing the available ground-water resources can be made as soon as the field exploratory work has been completed and the pumping-test data have been analyzed. The type of well best suited for a particular development depends chiefly on the character and thickness of the water-bearing formation, the depth at which the aquifer occurs and the anticipated yield and drawdown.

In unconsolidated sand formations wells are generally finished with a screen surrounded with an artificial gravel pack. Wells in many sand and gravel aquifers can be developed by surging to remove the fine materials in the formation so as to provide a natural gravel pack surrounding the screen.

The proper size of screen slot should be based on a sieve analysis of the water-bearing material or on the size of gravel to be used in the gravel pack. Screen manufacturers generally will recommend the proper slot size if they are furnished a representative sample of the aquifer. Often, the slot size selected is large enough to pass 60 percent or more of the water-bearing formation. The best type of screen generally has a high percentage of slot-opening area. In highly permeable sand and gravel aquifers, screens with

50 percent or more of slot-opening area are often used. If the well is to be artificially gravel packed, the size of gravel should be properly related to the natural formation. The gravel should be well-rounded and not too large in comparison to the screen slot size.

A chemical analysis of the water should be obtained to guide in determining the best material for the screen. Everdur or other corrosion-resistant material is often recommended by many screen manufacturers.

Where a permeable sand and gravel lies at relatively shallow depths and only small drawdown is available, horizontal collectors of large capacity may be constructed. These collectors consist of a large diameter vertical concrete caisson with horizontal perforated pipes extending out into the water-bearing formation. Installations of this type have advantages where the aquifer is thin or where the drawdown must be small to avoid drawing in salt water from greater depths. Many large-capacity horizontal collectors are in operation at sites where river infiltration can be induced.

In areas where the aquifer is hard bedrock containing fracture or solution openings, drilled wells are generally cased only near the surface. The entire open hole below the casing is free to yield water wherever there are openings.

One of the most important phases of constructing a well of high capacity involves the well-development process carried out for the purpose of removing all fine material in the formation near the well. If the pore spaces or fracture openings near the well are clogged with fine material, the friction loss that occurs as water moves toward the pumping well is greatly increased and this results in greater drawdown in the well than would otherwise be required.

Many wells subjected to short periods of development could be greatly increased in capacity if more effective methods of development were employed or if the period of development were considerably prolonged. Often several weeks or more are required to achieve maximum yield per foot of drawdown. The cost of prolonged development is often small as compared to the increased capacity obtained. Moreover, there is an additional saving because of the smaller pumping lift.

Well development, both in screened wells and in open-hole bedrock wells, is generally accomplished by a process of surging to break down the bridging of fine particles in the pore spaces or fracture openings in the aquifer. A variety of methods are used, such as, backwashing, surging with air or operating a surge-block in the well with a reciprocating motion. It is generally desirable to pump water from the well as the surging is carried on so that loosened particles will be removed from the well and not driven back into the aquifer. The amount of effective development accomplished by one day of surging often depends on the frequency of back surging rather than on the force of the surge action. Therefore, a day of surging with a pumping surge-block at say 20 strokes per minute may dislodge and remove far more fine material than a day of backwashing or air surging.

Some formations often yield turbid water that is difficult to eliminate during the well-development process. In many such cases, chemical treatment has successfully eliminated the turbidity. Solutions of a glassy phosphate, sodium chloride, calcium chloride and other chemicals have been used with good success. The best chemical for a particular well must be determined by experimentation. Generally, hydraulic surging should be used in conjunction with the chemical treatment.

Where the development of a ground-water supply involves two or more wells, the problem of well spacing arises. If a group of wells are too closely spaced excessive mutual interference will occur. The proper spacing between two operating wells varies greatly, depending chiefly on the characteristics of the aquifer. Under some conditions, a spacing of only a few hundred feet may be satisfactory but at other places a thousand feet or more may be desirable. The proper spacing can best be determined by pumping tests to establish the shape and extent of the cone of depression that will occur with anticipated periods and rate of pumping.

The choice of proper pump depends on the type and capacity of well and the drawdown. In those areas where a gradual but progressive decline of ground-water level is to be expected, pumping-test data can be used to predict future ground-water levels, thus indicating the proper depth of pump setting.

Maintenance and Observations

The proper operation of a ground-water development requires certain maintenance work and the making of hydrologic observations. Unless such a program is carried out, well capacities may gradually decrease or overpumping may unknowingly occur.

Records of the amount of water pumped should be kept. The pumping water level in all operating wells should be regularly measured. Samples of water for chemical analysis should be taken periodically. Regular observation of ground-water temperature may be desirable at installations utilizing river infiltration.

A gradual lowering of the pumping water level may be the result of seasonal declines of natural water levels or seasonal increases in pumping rate in the area. A period of dry years with less than average precipitation may result in a lowering of ground-water levels in no way related to the rate of pumping. However, if the total pumping in the area is excessive, ground-water levels will progressively decline.

At times, pumping water levels may gradually decline because of a decrease in well capacity rather than a lowering of water levels in the aquifer. Well screens may become clogged or corroded. The fracture or solution openings in an uncased bedrock well may gradually become obstructed. In order to determine whether a declining pumping water level is the result of decreased well capacity or dewatering of the aquifer, a non-pumping observation well should be maintained in each well field. Regular measurements of water level by tape or by means of a water-level recorder will show fluctuations of water level in the aquifer in no way related to changes in the capacity of pumping wells.

If there are indications of a decrease in well capacity, rehabilitation work should be undertaken. Heavy chlorination of the well screen and the material surrounding the screen may restore the original capacity if the decreased capacity is the result of bacterial growths. In some wells acid treatment has accomplished good results. Often, surging by various methods or treatment with chemicals may restore or considerably increase the capacity.

If the ground-water development is in an area where salt-water encroachment may be a problem, a systematic program of sampling each pumping well and all outpost wells should be carried on so that advance warning of any encroachment may be given.

The need for adequate and reliable observational data on the operation of a ground-water supply cannot be overemphasized. Sound operation requires a running knowledge of the condition resulting from heavy pumping. Moreover, if future increase in supply or other problems arise, such data will be available.

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